In Memory of Albert W. Overhauser (1925–2011)

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Albert W. Overhauser

Albert W. Overhauser, one of the best known and beloved pioneers in the development of magnetic resonance, passed away peacefully on 10 December 2011.

Born 17 August 1925 in San Diego, California, he attended high school in San Francisco. In 1942, he entered the University of California in Berkeley as a physics and mathematics major. He left college from 1942 to 1944 to serve in the United States Naval Reserve, training to be a radar repair specialist. Returning to college after the war, Overhauser graduated in 1948 and promptly entered Berkeley graduate school, also in physics. His thesis advisor, Charles Kittel, who was in the process of moving from Bell Labs to Berkeley, proposed as a thesis topic developing the theory of the spin–lattice relaxation time of the conduction electrons in metals. When Kittel finally arrived permanently at Berkeley in 1951, Overhauser

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presented him with the completed thesis. Kittel immediately placed a phone call to Frederick Seitz at the University of Illinois who offered Overhauser a post doctoral appointment doing experimental studies of radiation damage in solids working with Professor James Koehler. At this point, Overhauser asked his fiancée Margaret Mary Casey whether she could imagine leaving Berkeley to move to Illinois, a subtle but successful way to propose marriage.

At that time, Illinois was a hotbed of nuclear magnetic resonance (NMR) research. Erwin Hahn had gotten his PhD at Illinois in 1949, and stayed on for a year as a post doc after discovering spin echoes. Herbert Gutowsky had joined the Chemistry Department in 1948, a fresh PhD from Harvard where he had begun NMR research with Purcell's student George Pake. I had obtained my PhD in 1949 with Purcell, and joined the Physics Department at Illinois that fall. When Overhauser arrived, my first student, Dick Norberg, was just finishing his PhD thesis studying the ^1H NMR of hydrogen adsorbed in Pd metals. Overhauser got to know the resonance groups and learned about their studies of relaxation times in the alkali metals. In January 1952, he attended a talk by Norberg about his thesis. Overhauser reminisced to me: *"what Norberg said in his seminar was: the free induction decay contains information. I believed that, during the decay, the system is out of equilibrium (of course). So what I did in the next two days was to find out what happens when the system is held (steadily) out of equilibrium. (The discovery followed quickly)"*.

The discovery, now known as the Overhauser effect and also as dynamic nuclear polarization, was that one could increase the nuclear polarization in a metal 1,000-fold if one excited the resonance of the conduction electron spins sufficiently strongly. My students and I were amazed at this prediction and were eager to test it. As yet, no one had observed the magnetic resonance from conduction electrons in metals. In his thesis, Overhauser predicted a very narrow (0.1 G wide), intense electron spin resonance (ESR) signal. So, we immediately started searching various metals looking for such a narrow ESR signal using an NMR apparatus at 10 MHz and a correspondingly low magnetic field. In late 1952, Thomas W. Griswold, Arthur F. Kip, and Charles Kittel discovered the resonance, much broader than predicted, in metallic Na using 3 cm microwaves. Immediately thereafter, I found the ESR signal (5 G wide) in powdered Li metal, and my student Thomas R. Carver and I quickly embarked on an effort to verify Overhauser's predicted effect.

Overhauser pointed out that at low temperatures and in strong magnetic fields, large nuclear polarizations would shift the frequency of the ESR signal. He proposed looking for this frequency shift to verify his prediction. However, my group lacked the microwave and low-temperature equipment needed to carry out this method. Instead, we proposed a double resonance experiment in which we observed the effect on the ^7Li NMR of powdered Li metal produced by exciting the conduction electron ESR. This experiment could be done at room temperature and without microwave equipment. We required that the diameter of the metal particles be smaller than the electromagnetic skin depth for both electrons and nuclei, limiting the maximum frequency of ESR to approximately 100 MHz, requiring that the static magnetic field be about 30 G, and the NMR frequency near 50 kHz.

Overhauser presented his idea in a 10 min talk at the April 1953 meeting of the American Physical Society to an audience containing Felix Bloch (Nobel Prize in Physics 1952), Edward M. Purcell (Nobel Prize in Physics 1952), Nicolaas Bloembergen (future Nobel Prize in Physics 1981), Isidor I. Rabi (Nobel Prize in Physics 1944), Norman F. Ramsey (future Nobel Prize in Physics 1989), and Anatole Abragam. They were highly skeptical, perhaps suspecting that his idea violated the second law of thermodynamics. In June, Overhauser left Illinois to become assistant professor of physics at Cornell. He submitted a manuscript to *Physical Review* in late June. On 12th August, Tom and I first observed the enhancement (100-fold) of the ^7Li NMR signal. We sent a telegram to Overhauser telling the happy news and quickly submitted a paper. It was received at *Physical Review* on 17th August, Overhauser's 27th birthday.

Tom and I realized that the Overhauser effect required three elements: the relaxation time involves matrix elements of the spin–spin interaction between nucleus and electrons in which both spins were simultaneously flipped in going from the initial to the final spin states; there were degrees of freedom that could absorb the Zeeman energy difference between the initial and final spin states, and that there be an ESR signal that could be saturated. Thus, the Overhauser effect might be possible in a non-metallic liquid. In 1954, we demonstrated this, achieving a 100-fold enhancement of the polarization of protons in liquid ammonia in which we provided unpaired electron spins from dissolved Na atoms. Much of the present day dynamic polarization uses these principles. In 1955, Ionel Solomon demonstrated an Overhauser effect for a system whose spins consisting solely of nuclei (^{19}F and ^1H in the molecule HF). The nuclear Overhauser effect became very important in determining the structure of large biomolecules, as is evident in the Nobel Prize lecture of Kurt Wüthrich.

At Cornell, Overhauser was promoted to associate professor in 1956; but in 1958, he was lured by the physicist Jack Goldman to leave Cornell to join the research laboratory at Ford Motor Company. After Goldman left Ford to join Xerox in 1969 (and founded the Xerox Palo Alto Research Laboratory, with George Pake as its director), Overhauser remained at Ford just until 1973 when he became Professor of Physics at Purdue, a position he held until his death.

Throughout his career, he was deeply interested in simple metals. His last publication, in 2011, was a book titled *“Anomalous Effects in Simple Metals”* (Wiley–VCH), a compilation of the 65 papers he wrote on this topic.

He felt deeply honored to receive the Russell Varian Prize in 2009 for the invention of dynamic nuclear polarization. He was delighted at the exciting activity and many advances currently taking place in the field. In 2010, I was thrilled to be invited to prepare an historical article about the invention and demonstration of dynamic nuclear polarization for the journal *Physical Chemistry Chemical Physics* [PCCP **12**,5741(2010)]. I sent Al a copy and in return he sent me a copy of the telegram Tom and I sent him in August 1953. I am happy to report that he called me to say he enjoyed reading the PCCP article and reliving the exciting time we had together. I am sure that all workers in this field must feel as I do how fortunate it is that Al lived to see the field he invented so lively and so much a wave of the future.

Overhauser's many important contributions were honored by election both to the American Academy of Arts and Sciences and the National Academy of Sciences. He received the Oliver E. Buckley Solid State Physics Prize in 1975, the Alexander von Humboldt Senior Scientist Award (1979–1980), an Honorary Doctor of Science from the University of Chicago (1979), and an Honorary Doctor of Laws from Simon Fraser University in 1998. In 1994, President William Clinton presented him the United States National Medal of Science.